

New triple systems in the RasTyc sample of stellar X-ray sources ★,★★,★★★

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ABSTRACT

Context. During the study of a large set of late-type stellar X-ray sources, we discovered a large fraction of multiple systems.

Aims. In this paper we investigate the orbital elements and kinematic properties of three new spectroscopic triple systems as well as spectral types and astrophysical parameters (T_{eff} , $\log g$, $v \sin i$, $\log N(\text{Li})$) of their components.

Methods. We conducted follow-up optical observations, both photometric and spectroscopic at high resolution, of these systems. We used a synthetic approach and the cross-correlation method to derive most of the stellar parameters.

Results. We estimated reliable radial velocities and deduced the orbital elements of the inner binaries. The comparison of the observed spectra with synthetic composite ones, obtained as the weighted sum of three spectra of non-active reference stars, allowed us to determine the stellar parameters for each component of these systems. We found all are only composed of main sequence stars.

Conclusions. These three systems are certainly stable hierarchical triples composed of short-period inner binaries plus a tertiary component in a long-period orbit. From their kinematics and/or Lithium content, these systems result to be fairly young.

Key words. stars: binaries (including multiple): close – stars: binaries: spectroscopic – X-rays: stars – stars: late-type – stars: fundamental parameters – techniques: radial velocities

1. Introduction

Binary and multiple stars are very important astrophysical laboratories. In particular, spectro-photometric and spectro-astrometric binaries offer the unique opportunity to determine, with a high level of accuracy, the basic stellar parameters (mass, radius, and effective temperature) to study stellar structure and evolution. However, the formation and evolution of binary stars are still debated subjects (e.g., Zinnecker & Mathieu, 2001). Especially, a still unsolved problem is the formation of close binaries with main sequence components separated by few solar radii that in the proto-stellar phase should have been in contact.

In the last years, to answer many of these open questions, relevant observational and theoretical efforts are being done to improve continuously the statistics of binary systems with different periods, mass ratios, etc. (e.g., Tokovinin et al., 2006).

Close binaries containing at least one late-type component, such as RS CVn and BY Dra systems, are objects with the strongest magnetic activity (starspots, plagues, flares) induced by

a dynamo action in the sub-photospheric convection zone. Their strong activity is mainly due to their very fast rotation (spin-orbit synchronization by tidal forces) and to proximity effects.

X-ray sky surveys performed in recent years have allowed to identify thousands of active late-type stars in the field and in open clusters. Follow-up observations of the optical counterparts of X-ray sources have led to discover very young stars far from the typical birth sites, i.e. open clusters and stars forming regions (e.g., Wichmann et al., 2003a; Zickgraf et al., 2005; Torres et al., 2006; Guillout et al., 2008), as well as to detect several spectroscopic binaries (e.g., Wichmann et al., 2003b; Frasca et al., 2006). The knowledge of the incidence of binaries and multiple systems in X-ray selected samples of active stars is extremely important to study the recent local star formation history.

One of the largest ($\sim 14\,000$ active stars) and most comprehensive set of stellar X-ray sources in the field is the so-called RasTyc sample, which is the result of the cross-correlation of the ROSAT All-Sky Survey (RASS) with the TYCHO catalog (Guillout et al., 1999). We began to analyze a representative sub-sample of the RasTyc population in the northern hemisphere (Guillout et al., 2008) to obtain some reliable statistics about the RasTyc stellar characteristics. For this purpose, we led campaigns of high-resolution spectroscopic observations, with the ELODIE échelle spectrograph at the 193-cm telescope and the AURELIE spectrograph at the 152-cm telescope of the Observatoire de Haute Provence (OHP). For all the sources, we performed a detailed analysis of the cross-correlation function (CCF) and found that single-lined (SB1), double-lined (SB2), and triple-lined (SB3) spectroscopic systems altogether account

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* Based on observations collected at the Observatoire de Haute Provence (France) and the M. G. Fracastoro station (Serra La Nave, Mt. Etna, 1750 m a.s.l.) of the Catania Astrophysical Observatory (Italy)

** Tables 2 to 4 are available in electronic form at the CDS via anonymous FTP to cdsarc.u-strasbg.fr (130.79.128.5) or via <http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/> as well as via <http://www.edpsciences.org/>

*** Figures 1–4 and 8 are only available in electronic form via <http://www.edpsciences.org/>

Table 1. Main data of the three *RasTyc* sources from the literature.

<i>RasTyc</i> Name	Name	α (2000) (h m s)	δ (2000) (° ' ")	V_r^a (mag)	π^b (mas)	μ_α^a (mas yr ⁻¹)	μ_δ^a (mas yr ⁻¹)	X-ray source 1RXS	Counts (ct s ⁻¹)
RasTyc 0524+6739	BD+67 381	05 24 53.2	+67 39 39	9.065	7.8±9.3	-0.5	26.7	J052454.0+673939	4.21×10 ⁻¹
RasTyc 1828+3506	BD+35 3261	18 28 50.3	+35 06 34	9.049	12.2±8.2	12.3	-3.5	J182849.7+350637	6.24×10 ⁻²
RasTyc 2034+8253	BD+82 622	20 34 27.5	+82 53 35	9.730	—	61.5	35.5	J203426.2+825334	3.75×10 ⁻¹

^a V magnitude and proper motions from the TYCHO-2 catalog (Høg et al., 2000); ^b Parallax from the TYCHO-1 catalog (ESA, 1997)

for more than 35 % of the sample. In particular, at least 10 sources are clearly identified as triple systems. Our aim is to determine the orbital and physical parameters of these systems. For this reason, we have monitored these new multiple systems, both photometrically and spectroscopically, with the 91-cm telescope of the *Osservatorio Astrofisico di Catania* (OAC).

The majority of the triple systems studied so far are nearby objects and look as visual binaries where one component is a SB2 system. Here we study three of such newly discovered SB3 late-type systems for which we obtained enough data. A detailed analysis of the entire sample of stellar X-ray sources and of the multiple systems discovered so far is necessary for drawing statistically significant conclusions. Nevertheless, the properties of these three systems can give us some insights into the typical composition of triple systems among stellar X-ray sources.

The paper is organized as follows. We summarize briefly the observations and their reduction in Sect. 2. The determination of radial velocity and physical parameters ($v \sin i$'s, Lithium abundances, etc.) are shown in Sect. 2 as well. The photometric modulation, the spectral composition, and the age estimate are discussed in Sect. 3. The conclusions are outlined in Sect. 4.

2. Observations and spectral analysis

These three systems belong to the *RasTyc* sample of stellar X-ray sources (Guillout et al., 1999). Their spectra, acquired at different dates, show alternatively a triple-line or a single-line pattern (Fig. 1)¹, that is the unambiguous signature of SB3 systems. Table 1 lists the most relevant information from the literature. In the following, we briefly outline the observations and analysis methods and refer to Guillout et al. (2008) for a detailed description.

2.1. Observations and data reduction

Spectroscopic observations were first conducted at the OHP between 2001 and 2005 with the AURELIE spectrograph (Gillet et al., 1994) within the framework of a key program on the coudé 152-cm telescope. We used grating #7, which yields a high spectral resolution, $R = \lambda/\Delta\lambda$, of about 38 000 in the wavelength range of our observations, i.e. both in the H α (6490–6630 Å) and the Lithium (6650–6780 Å) spectral regions. We obtained 16, 15 and 18 spectra for RasTyc 0524+6739, RasTyc 1828+3506 and RasTyc 2034+8253, respectively. The signal-to-noise ratio, S/N, was in the range 70–200. All these spectra were reduced using standard MIDAS procedures.

The observations at the OAC were carried out from 2004 to 2006 with the FRESKO échelle spectrograph mounted on the 91-cm telescope. The spectral resolution, as deduced from

the FWHM of the lines of the Th-Ar calibration lamp, is $R \approx 21\,000$. The 300-line/mm cross-disperser allowed to record about 2500 Å at a time. The 19 échelle orders recorded by the CCD cover the 4310–6840 Å spectral region. We obtained 13, 6, and 12 spectra for RasTyc 0524+6739, RasTyc 1828+3506, and RasTyc 2034+8253, respectively, with a S/N ranging from 30 to 100, depending on the star magnitude and sky conditions. In any case, giving the wide spectral range, the S/N was always adequate to perform good radial velocity (RV) measurements. The reduction of all these spectra was performed using the ÉCHELLE task of IRAF² package.

Photometric observations were carried out from 2004 to 2006 in the standard *UBV* system with the 91-cm telescope of OAC. For each field of the three *RasTyc* sources studied here, we chose two or three stars with known *UBV* magnitudes to be used as local standards for determining the photometric instrumental “zero points”. Additionally, several standard stars, selected from the list of Landolt (1992), were also observed during the run in order to determine the transformation coefficients to the Johnson standard system. The data were reduced by means of the photometric data reduction package PHOT designed for the photoelectric photometry of OAC (Lo Presti & Marilli, 1993). The errors are typically $\sigma_V = 0.006$, $\sigma_{B-V} = 0.008$, and $\sigma_{U-B} = 0.010$.

2.2. Radial and projected rotational velocities determination

From the analysis of the CCF (Figs. 2, 3, and 4)¹, we could accurately measure the RV and the projected rotational velocity ($v \sin i$) of each one of the stellar components. The RV measurements of these new systems are listed in Tables 2–4¹ together with their standard errors.

2.3. Spectral types and stellar parameters

With the aim to have a first guess of the spectral types of these objects, we applied the ROTFIT code (Frasca et al., 2003, 2006) to spectra for which only one peak is visible in the CCF.

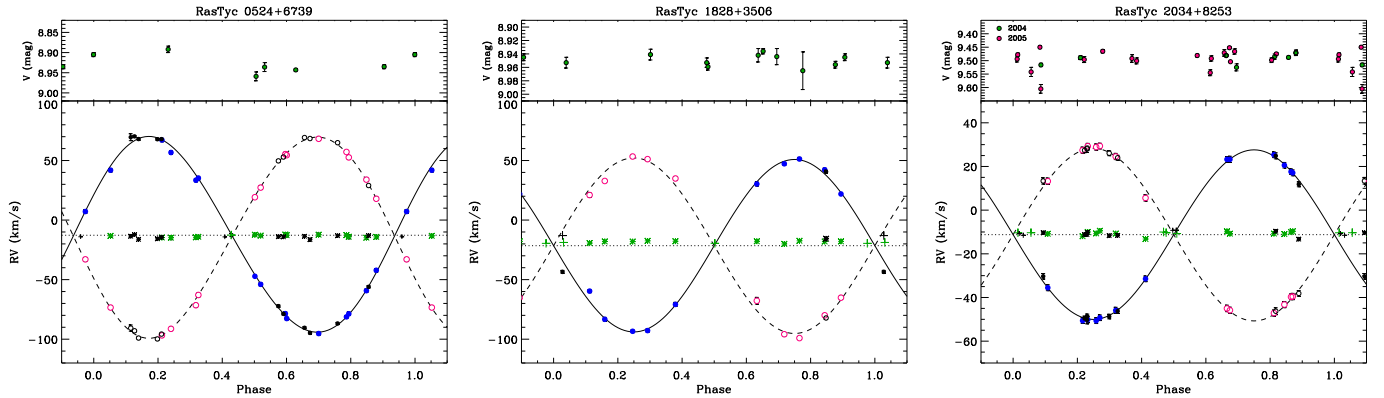
For the evaluation of the spectral type of each individual component, we analyzed the spectra for which the CCF shows three distinct peaks. We used another IDL code, similar to ROTFIT, to estimate the spectral type, the astrophysical parameters (APs), and the continuum flux contribution of the tertiary component. The subtraction of the spectrum fitted to this component provided us with a “cleaned” spectrum of the inner binary that we could analyze with COMPO2 (Frasca et al., 2006) in the

² IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

¹ Available in electronic form only.

Table 5. Orbital parameters of the three systems. The errors on the last significant digit are enclosed in parenthesis. P = Primary and S = Secondary.

Name	HJD0 (2 450 000+)	P_{orb} (days)	e	ω ($^{\circ}$)	γ (km s^{-1})	k (km s^{-1}) [P/S]	$M \sin^3 i$ (M_{\odot}) [P/S]	M_P / M_S
RasTyc 0524+6739	2212.02(5) ^a	3.65884(2)	0.042(3)	294(5)	-13.4(2)	82.2(3)/84.5(3)	0.889(6)/0.865(6)	1.028(4)
RasTyc 1828+3506	3565.95(4) ^b	7.595(5)	0	—	-21.5(4)	72.4(5)/73.7(5)	1.24(2)/1.22(2)	1.018(9)
RasTyc 2034+8253	2471.3(3) ^b	4.9543(2)	0	—	-11.2(3)	38.8(3)/39.5(3)	0.124(2)/0.122(2)	1.02(1)

^a Heliocentric Julian Date (HJD) of the periastron passage; ^b HJD of the inferior conjunction of the primary (more massive) component.**Fig. 5.** Radial velocity curves of the new three *RasTyc* triple systems. Large symbols refers to AURELIE data while smaller symbols are used for FRESKO spectrograph data. Filled and open circles for the primary (more massive) and secondary component of the inner binaries have been used, respectively. In each panel, the solid and dashed lines represents the orbital solutions for the primary and secondary component, respectively, whereas the dotted line represents the barycenter of the inner binary. The asterisks are used for the tertiary component and plus symbols refer to blended RV values. The RV errors are always smaller than, or comparable to, the symbol size. The V photometry is displayed, as a function of the orbital phase, on the top panel of each box.

usual way. In Sect. 3.3, we discuss the results of this procedure concerning the spectral type and the contribution to the continuum flux (weight) as well as the values (the weighted mean of the best 100 combinations) of the APs, namely the effective temperature (T_{eff}), gravity ($\log g$), and metallicity ($[\text{Fe}/\text{H}]$), for the three components of each triple system.

Moreover, we applied the “spectral subtraction” technique (e.g., Frasca & Catalano, 1994; Montes et al., 1995) to measure the Li I equivalent width, $EW(\text{Li})$, of each stellar component (Fig. 7, bottom of each box) and used the Pavlenko & Magazzù (1996) calculations to deduce a Lithium abundance, $\log N(\text{Li})$. From these parameters, we estimated the age of these three systems in Sect. 3.4.

3. Results and discussion

3.1. Orbital solutions

We initially searched for eccentric orbits and we found low eccentricity values ($e = 0.042 \pm 0.003$, $e = 0.026 \pm 0.007$, and $e = 0.020 \pm 0.012$ for RasTyc 0524+6739, RasTyc 1828+3506, and RasTyc 2034+8253, respectively). Following the precepts of Lucy & Sweeney (1971, Eq. 22), we considered as significant only the eccentricity of RasTyc 0524+6739 and adopted $e = 0$ (circular orbits) for the other two systems. The CURVEFIT routine (Bevington, 1969) was used to fit the observed RV curves and to determine the orbital parameters and their standard errors for

each inner binary (Table 5). The observed RV curves of the three triple systems are displayed in Fig. 5.

For the two RasTyc systems with the shortest orbital periods, the RV value of the tertiary component is very close to the barycentric velocity (γ) of the inner binary during different observing seasons. Thus, we could not try any evaluation of the orbital period of the tertiary component. As the vast majority of the already known triple systems, each of our sources consists of a short-period inner binary with a third component orbiting around the close pair in a long-period orbit. These systems display a typical “hierarchical” configuration (Evans, 1968). In particular, RasTyc 2034+8253 was already known as a visual binary (Muller, 1976). From the observations of Muller (1976, 1978, 1990) and Fabricius et al. (2002), this component seems to have a regular evolution because the position angle and the separation are constantly growing. Thus, its orbital period must be significantly greater than the period of observations (about 20 years) implying a degree of hierarchy $X \gg 1500$, where X is defined as the ratio of the “external” period (orbit of tertiary component around the center of mass to the inner binary) to the “internal” period (that of the inner binary).

On the contrary, in 2005, the tertiary component of RasTyc 1828+3506 displays a RV systematically higher (3.3 km s^{-1}) than that of the barycenter of the inner binary (see Fig. 5, middle panel). Moreover, we found a highly significant RV increase (more than 15 km s^{-1}) for the tertiary com-

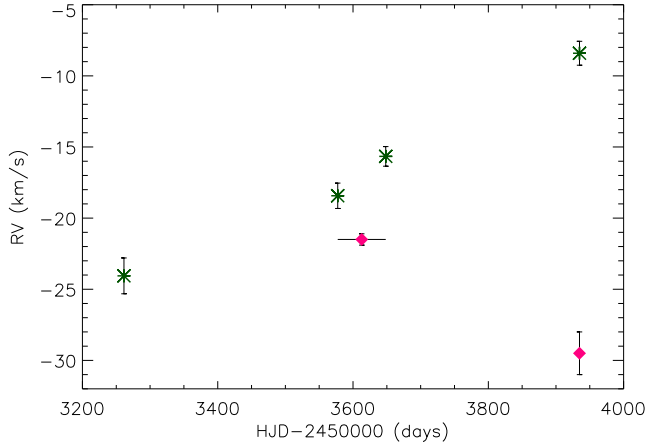


Fig. 6. RV variation for the tertiary component of RasTyc 1828+3506 (asterisks) during the four seasons of observations which span from 2004 to 2006. The barycenter RV of the inner binary in 2005 and 2006 is also displayed by two diamonds.

ponent during the four seasons of observations (Fig. 6). This relevant RV variation prevented us from using all the RV values to obtain the orbital solution of the inner binary. Thus, we deduced the orbital parameters from the solution of OHP and OAC data acquired in 2005 only. The four RVs obtained at OAC in 2006 allowed us to estimate the barycentric velocity $\gamma = -29.5 \pm 1.5 \text{ km s}^{-1}$ at that epoch, by adopting the values of semi-major axes, $k_P = 72.4 \text{ km s}^{-1}$ and $k_S = 73.7 \text{ km s}^{-1}$, found from the solution of 2005 data. We could not evaluate the orbital period of the tertiary, but, from the data trend, we can argue that the period must be larger than 6 years (but presumably shorter than some tens years) implying $X \geq 300$. New observations will enable us to obtain the solution for the tertiary orbit.

Using the empirical stability criterion described by Orlov & Petrova (2000), we can conclude that these three newly discovered triple systems are in a gravitationally stable orbital configuration.

3.2. Photometric variability

The photometric monitoring of our sources in *UBV* bands allowed us to determine the mean magnitudes and color indices as well as to detect any eventual variability. The average values of V , $B - V$, and $U - B$ are reported in Table 6.

RasTyc 0524+6739, the system with the shortest orbital period, is the only one showing a clear variation that is likely correlated with the orbital period. Unfortunately, because of poor weather conditions during the winter observing season, the photometric data were obtained only on six nights and are not sufficient to cover evenly the light curve. However, we estimated the amplitude of the V light curve to about $0^m.07$.

For RasTyc 1828+3506 and RasTyc 2034+8253 there is no indication of rotational modulation in the V magnitude, in spite of the larger number of data. However, some indication of a stochastic variation comes out for RasTyc 2034+8253, whose magnitude varies in the range $9^m.45 - 9^m.60$ with errors lower than $0^m.02$. No clear periodicity was found in these data.

The detection of a V modulation only on the system with the shortest orbital period ($P_{\text{orb}} \approx 3.6$ days) is in line with the

Table 6. Photometric data and distance determination for the three systems. The error on the last significant digit is enclosed in parenthesis.

Name	V (mag)	$B - V$ (mag)	$U - B$ (mag)	Dist. (pc)
RasTyc 0524+6739	8.892(7) ^a	0.773(7)	0.235(9)	75 ± 20
RasTyc 1828+3506	8.951(8)	0.578(6)	0.015(8)	115 ± 25
RasTyc 2034+8253	9.49(2)	0.96(1)	0.70(3)	80 ± 20

^a V magnitude at maximum brightness.

well established enhancement of magnetic activity in the components of close binaries due both to fast rotation and nearness. Moreover, tidal interaction in these binaries leads to synchronization between orbital and rotational periods of both components. It is worth noticing that the periods of all these three systems are smaller than, or very close to, the cut-off value of 7.56 days found by Melo et al. (2001) for orbital circularization in Pre-Main Sequence (PMS) binaries. According to Zahn & Bouchet (1989), for close late-type binaries with masses ranging from 0.5 to $1.25 M_{\odot}$, the cut-off period may be as long as 7.2 to 8.5 days, depending on the masses and on the assumptions of the initial conditions. So, being all these systems older than PMS stars, they should be already circularized, in substantial agreement with the results from the solution of their RV curves. The non-detection of photometric variation in RasTyc 1828+3506 could be related both to the fairly long orbital/rotational period (7.595 days) and to the relatively early spectral types of the system components with shallower convective envelopes and, consequently, with a reduced dynamo action compared to cooler stars with the same rotation rate.

3.3. Astrophysical parameters and other properties

The use of ROTFIT and COMPO2 codes allowed us to derive the spectral type and the APs for the components of each system (Table 7). We used spectra of stars of the same spectral types retrieved from the ELODIE Archive (Prugniel & Soubiran, 2001) to build up the reference spectra displayed in Fig. 7. Moreover, the relative continuum contributions of the tertiary components are in agreement with their spectral types found by us, taking into account the errors derived from the distribution of the best spectral combinations. This uncertainty is about 1.5 spectral subclasses, except for the tertiary component of RasTyc 0524+6739, the coolest star, for which the uncertainty is more than 2 spectral subclasses. Regarding $\log g$ and $[\text{Fe}/\text{H}]$, despite the rather large errors, we can state that the three systems are composed of MS stars with a nearly solar metallicity.

We found that the weight for the components of all inner binaries is nearly equal (Table 7), i.e. their luminosity ratio is ≈ 1 . This is compatible with the mass ratio ($M_P/M_S \approx 1$) (Table 5) derived from the solution of the RV curves, if the two *twin* stars are both on the MS. Our results, although not statistically significant, are in favor of an excess of twins in spectroscopic binaries containing a third body as suggested by Tokovinin et al. (2006). Moreover, the CCF dips of RasTyc 1828+3505 and RasTyc 2034+8253 would suggest a tertiary component brighter than each star of the inner binary. However, the weights quoted in Table 7 for RasTyc 1828+3505 are in conflict with the depth

Table 7. Physical parameters for each component of the three systems.

Component	Primary (P)	Secondary (S)	Tertiary (T)
RasTyc 0524+6739 :			
T_{eff} (K)	5350 ± 280	5270 ± 270	4700 ± 450
$\log g$	4.2 ± 0.3	4.2 ± 0.4	4.2 ± 0.4
$[Fe/H]$	-0.21 ± 0.18	-0.24 ± 0.21	-0.12 ± 0.11
$v \sin i$ (km s $^{-1}$)	12 ± 2	12 ± 3	< 5
Weight	0.45 ± 0.05	0.43 ± 0.05	0.12 ± 0.02
Sp. Type	G9V	G9V	K5V
RasTyc 1828+3506 :			
T_{eff} (K)	5800 ± 400	5800 ± 350	5480 ± 300
$\log g$	4.2 ± 0.2	4.2 ± 0.2	4.3 ± 0.2
$[Fe/H]$	-0.27 ± 0.17	-0.24 ± 0.18	-0.21 ± 0.12
$v \sin i$ (km s $^{-1}$)	12 ± 1	11 ± 2	< 5
Weight	0.38 ± 0.08	0.33 ± 0.08	0.29 ± 0.03
Sp. Type	G1V	G1V	G4V
$EW(\text{Li})$ (mÅ)	—	—	49 ± 15
$\log N(\text{Li})$	—	—	$1.8 - 2.0$
RasTyc 2034+8253 :			
T_{eff} (K)	4960 ± 260	4920 ± 300	5090 ± 200
$\log g$	4.3 ± 0.2	4.4 ± 0.2	4.4 ± 0.2
$[Fe/H]$	-0.23 ± 0.24	-0.23 ± 0.23	-0.05 ± 0.17
$v \sin i$ (km s $^{-1}$)	< 5	< 5	< 5
Weight	0.31 ± 0.04	0.30 ± 0.04	0.39 ± 0.04
Sp. Type	K3V	K3V	K1V
$EW(\text{Li})$ (mÅ)	72 ± 20	76 ± 10	96 ± 14
$\log N(\text{Li})$	$1.9 - 2.0$	$1.9 - 2.0$	$1.9 - 2.0$

of the CCF dips. The inconsistency is removed if we take into account the earlier spectral type and the faster rotation of the components of the inner binary of this system compared to the tertiary star.

We used the nomenclature proposed by Lafrenière et al. (2008) assigning the letter A to the brightest (more massive for MS stars) component and enclosing in parentheses the components forming the inner binary. We found one system (RasTyc 2034+8253) and two systems (RasTyc 0524+6739 and RasTyc 1828+3506) in the A,(B,C) and (A,B),C configurations, respectively. Although our sources appear to be older than PMS stage (Sect. 3.4), the configurations found are similar to those typically encountered in PMS stars (Lafrenière et al., 2008; Correia et al., 2006). Moreover, Mayor & Mazeh (1987) and Tokovinin et al. (2006) found that the most massive component in the multiple stellar systems is preferentially in the close binaries. In particular, Tokovinin et al. (2006) found a small fraction of systems ($17 \pm 4\%$) where the spectroscopic primary is not the most massive star.

Our results seem to be consistent with those of these authors and need to be confirmed with a larger statistical sample of multiple systems. The analysis of all the triple systems found by us in the RasTyc sample, for which we are still collecting RV data, will help us to confirm these findings.

3.4. Age estimation and kinematics

It is well established, for stars later than about mid-G spectral type, that the strength of the Li I $\lambda 6707.8$ line can be used

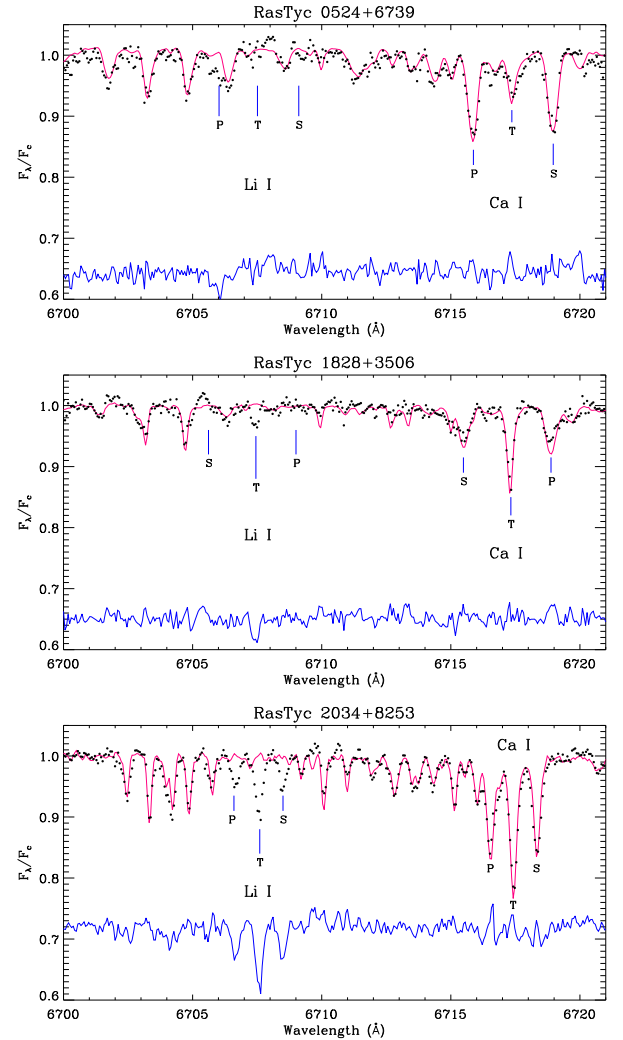


Fig. 7. The spectral region containing the Li I $\lambda 6707.8$ and the Ca I $\lambda 6717.7$ lines in a high-resolution spectrum of the three triple systems (dots). The reference spectrum built up with the weighted sum of three standard-star spectra (Table 7) is shown superimposed by a thin line. The Lithium and Calcium lines for the three components of this system are also marked by vertical lines. We note the absence of three Li I absorption lines in each reference spectrum. Each box also displays at the bottom the difference (observed - synthetic) with a thin line.

as an age estimator, a high $\log N(\text{Li})$ being a youth indicator. Although the Lithium abundance can not be simply converted into age, we can give a rough evaluation of the age by comparing the $\log N(\text{Li})$ value of our systems (Table 7) to that of Pleiades and Hyades stars having the same temperature (see, e.g., Soderblom et al., 1993; Jeffries, 2000). We report the estimated age in Table 8.

The parallax (π) from TYCHO-1 catalog (ESA, 1997) are not enough accurate. Thus, we estimated photometric distances (Table 6) from the “integrated” V magnitude measured by us and the mean V absolute magnitude for each triple system. The precision of proper motions for these systems is 1.5 mas yr^{-1} in TYCHO-2 catalog (Høg et al., 2000). From these two parameters and barycentric RVs of the inner binary, we computed the space-velocity components (U, V, W) of these SB3s in the left-handed coordinate system. Their space velocities are con-

Table 8. Kinematic parameters of the new triple systems.

Name	Age (Myr)	U (km s ⁻¹)	V (km s ⁻¹)	W (km s ⁻¹)	Moving Group	Probability (%)
RasTyc 0524+6739	> 600	-16.1 ± 1.9	-1.1 ± 1.9	0.6 ± 1.5	UMa	5 – 35
RasTyc 1828+3506	400 – 600	8.5 ± 1.0	-15.6 ± 1.0	-13.7 ± 1.9	Pleiades	25 – 55
RasTyc 2034+8253	100 – 300	19.1 ± 4.1	-14.0 ± 2.0	-17.3 ± 4.8	IC 2391	5 – 15

sistent with those of the young-disk (YD) population (Fig. 8)¹. Based on two kinematics methods (Klutsch et al., 2008), we determined the membership probability (Table 8) to five young Stellar Kinematic Groups (SKGs; Montes et al., 2001).

For RasTyc 0524+6739, we did not observe any Li I absorption lines in the spectra (Fig. 7, top panel), notwithstanding the spectral types of its components that would permit the detection of the Li I line also with a moderate abundance. Thus, this system should be older than the Hyades. Therefore, even though its position in the UVW diagrams points to a marginal association with the young Ursa Major (UMa) group ($Age \sim 300$ Myr), we do not consider this star as a new member of this SKG.

Trusting only the kinematics, RasTyc 1828+3506 could be a new member of the Pleiades moving group ($Age \sim 100$ Myr), whose members display strong Lithium absorption. However, this is not consistent with the non-detection of Li I absorption lines in the spectra of RasTyc 1828+3506, except for the tertiary component (Fig. 7, middle panel). The $\log N(\text{Li})$ value we deduce for it is only slightly higher than that of Hyades stars. Therefore, the age of the system could be in the range 400 – 600 Myr, ruling out its membership to the Pleiades moving group.

Finally, even though the RasTyc 2034+8253 kinematics is marginally consistent with that of the already known members of IC 2391 supercluster, we can clearly distinguish the Lithium lines for the three components (Fig. 7, lower panels). The $\log N(\text{Li})$ value found for its three components is very similar and reinforce the idea of a common origin for all the components. This value is only slightly lower than that of Pleiades stars. Therefore, we estimate an age between 100 and 300 Myr which is compatible with that of two stellar populations in IC 2391 supercluster (Eggen, 1991). The agreement between the kinematic age and that inferred from the Lithium suggests that this system can be a possible new member of this SKG.

4. Conclusions

This paper is devoted to the analysis of three new triple systems discovered in the RasTyc sample of stellar X-ray sources. Their spectroscopic and photometric data allow us to conclude that they are almost certainly stable hierarchical triple systems composed of short-period inner binaries plus a tertiary component in a long-period orbit. The orbital periods of the inner binaries range from 3.5 to 7.6 days and the orbits are practically circular. From the high-resolution spectra we also found the spectral composition and the astrophysical parameters of the components that turn out to be all G-K main sequence stars. In all cases, the components of the inner binaries have nearly the same masses, spectral types, and luminosities. From their kinematics and/or Lithium content, these systems result to be fairly young. RasTyc 2034+8253 is the only system in which the Li I $\lambda 6707.8$ line is strong enough to be clearly visible in

the spectra of all the three components and suggests an age in the range 100 – 300 Myr. It is a possible new member of the IC 2391 supercluster. For the remaining systems, the membership to young moving groups is rather uncertain.

Our spectroscopic survey has revealed that multiple systems represent a large fraction of the RasTyc sources. However, a detailed analysis is absolutely necessary for drawing statistically significant conclusions. Since RasTyc objects are relatively nearby, the discovery and the study of new triple systems, such as those presented in the present paper, can contribute to a better understanding of the formation and the evolution of close binaries and multiple systems in the solar neighborhood.

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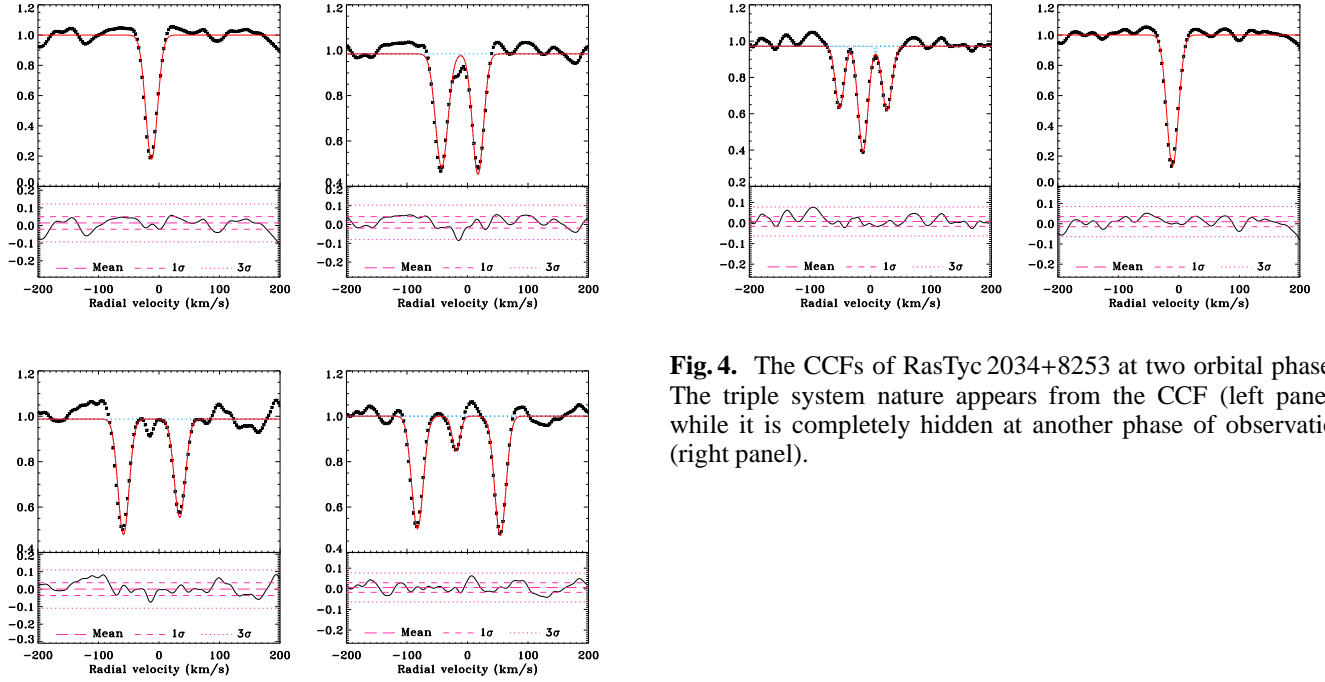


Fig. 2. The CCFs of RasTyc 0524+6739 permit to emphasize the change of configuration from a one-peak shape at a conjunction (left top panel) to a three-peak shape (right lower panel), passing through phases of partial blending in which only two peaks are easily distinguishable (left lower panel and right top panel). The RV uncertainty is about 1 km s^{-1} at our spectral resolution. On each panel, the multiple Gaussian fits of the CCFs are overplotted with full lines (top box) and the residuals of the fits are plotted in the lower box.

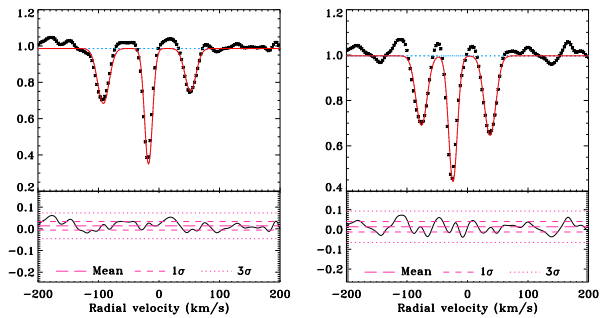


Fig. 3. The CCFs of RasTyc 1828+3506 clearly show three peaks with different widths. The two components of the inner binary appear to rotate faster than the third star, probably due to spin-orbit synchronization.

Fig. 4. The CCFs of RasTyc 2034+8253 at two orbital phases. The triple system nature appears from the CCF (left panel), while it is completely hidden at another phase of observation (right panel).

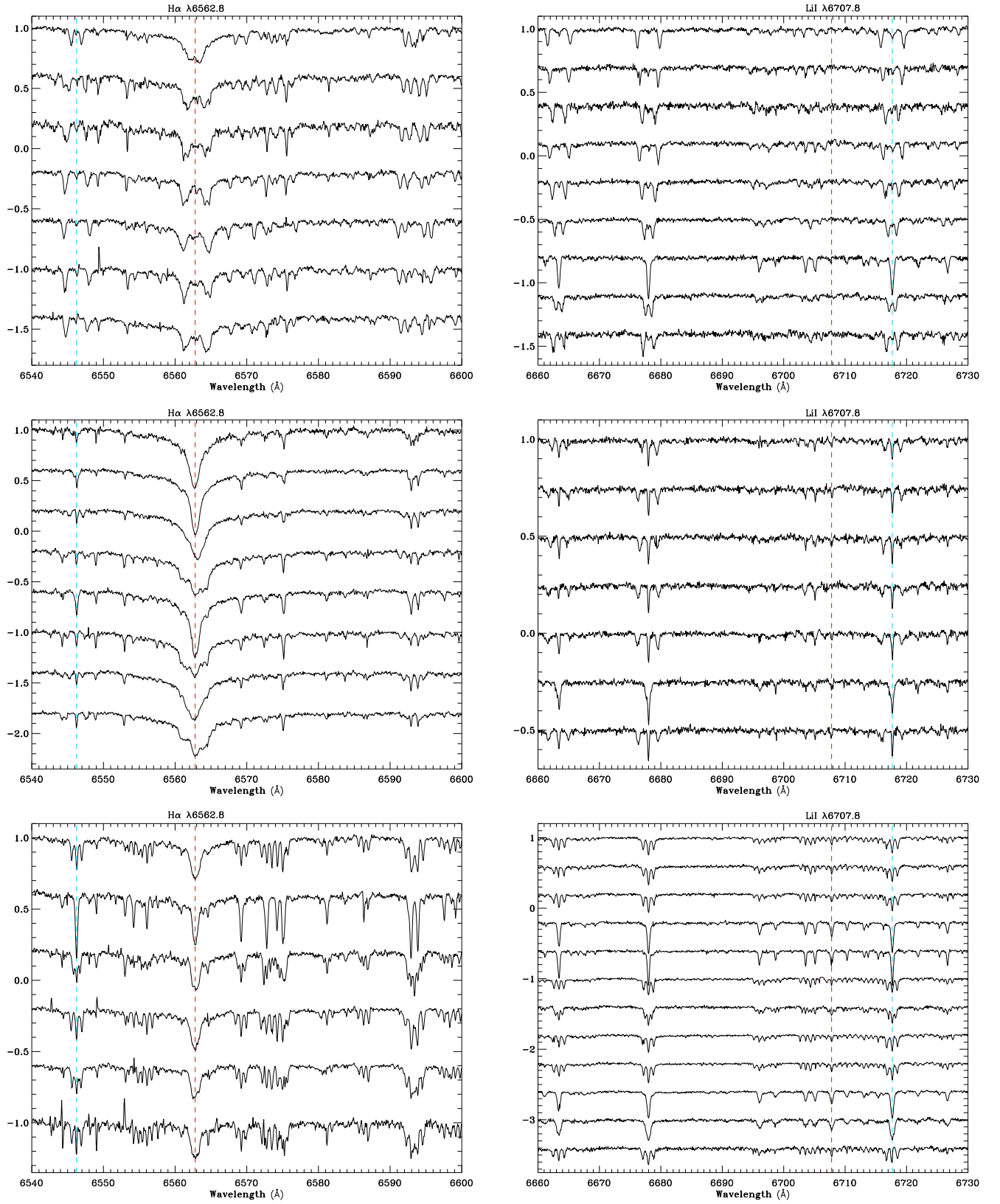


Fig. 1. High resolution spectra of RasTyc 0524+6739 (top panels), RasTyc 1828+3506 (middle panels) and RasTyc 2034+8253 (lower panels) acquired with the AURELIE spectrograph at the 152-cm telescope of the OHP both in the H α (left panels) and the Lithium spectral regions (right panels). The laboratory wavelengths of the Fe I $\lambda 6546.2$ and the H α lines as well as those of the Li I $\lambda 6707.8$, and the Ca I $\lambda 6717.7$ are marked with vertical dashed lines in the H α and Lithium spectral regions, respectively.

Table 2. Radial velocity of the primary (more massive, v_p), secondary (v_s), and tertiary (v_t) components of RasTyc 0524+6739 from Aurelie (OHP) and FRESCO (OAC) spectra. The orbital phase has been computed according to the ephemeris $HJD_{\text{inf.conj.}} = 2\,451\,997.7654 + 3.6587 \times E$, with zero phase corresponding to the inferior conjunction for the primary component.

H.J.D. ^a (2450000+)	Phase	v_p (km s ⁻¹)	Δv_p	v_s (km s ⁻¹)	Δv_s	v_t (km s ⁻¹)	Δv_t	Obs ^c
2216.45508	0.773	67.22	1.47	-96.83	1.51	-14.69	1.50	OHP
2217.51416	0.062	-47.21	0.96	19.18	0.76	-12.33	0.77	OHP
3570.57544	0.882	33.45	1.35	-71.51	1.58	-14.50	1.30	OHP
3571.60986	0.165	-82.68	1.18	54.48	1.17	-12.72	1.37	OHP
3572.51733	0.413	-59.27	1.30	33.95	1.30	-14.78	1.40	OHP
3579.60791	0.351	-81.26	1.12	57.18	1.11	-12.64	1.12	OHP
3580.57983	0.617	41.87	1.47	-73.43	1.46	-13.26	1.20	OHP
3581.57983	0.890	35.23	1.46	-62.89	1.50	-14.08	1.20	OHP
3582.57056	0.161	-78.56	1.52	55.35	1.52	-12.17	1.70	OHP
3583.60596	0.444	-42.14	1.46	17.90	1.47	-14.14	1.40	OHP
3585.61300	0.992	— ^b	—	—	—	-12.60	1.24	OHP
3586.60889	0.264	-95.28	1.31	68.24	1.42	-12.29	1.30	OHP
3587.61035	0.538	7.17	1.50	-32.99	1.53	—	—	OHP
3588.58545	0.805	56.72	1.52	-91.28	1.51	-14.80	1.60	OHP
3589.60693	0.084	-53.96	1.42	27.28	1.51	-13.05	0.90	OHP
3590.61060	0.358	-78.68	1.47	52.60	1.52	-14.00	1.70	OHP
3782.34390	0.763	67.87	0.96	-99.81	0.98	-15.74	2.28	OAC
3791.33690	0.221	-90.43	0.82	69.26	0.90	-13.63	1.53	OAC
3792.44580	0.524	— ^b	—	—	—	-14.02	0.61	OAC
3798.41420	0.155	-78.78	0.84	52.93	0.85	-14.10	1.85	OAC
3799.38410	0.420	-56.04	0.88	29.01	0.89	-13.11	1.77	OAC
3800.33420	0.680	69.56	2.89	-90.69	2.64	-13.54	4.16	OAC
3809.33300	0.140	-72.26	1.01	49.68	0.96	-13.97	1.58	OAC
3811.39950	0.705	68.02	1.02	-99.04	0.98	-16.24	2.47	OAC
3812.38150	0.973	— ^b	—	—	—	-14.13	0.46	OAC
3826.29570	0.776	67.96	0.60	-95.73	0.64	-14.50	0.92	OAC
3828.30120	0.324	-86.83	0.89	64.96	0.87	-13.16	1.87	OAC
3833.30580	0.692	70.25	0.77	-92.96	0.88	-12.26	1.75	OAC
3835.30440	0.238	-94.74	0.96	68.45	0.89	-16.45	1.91	OAC

^a Heliocentric Julian date at mid exposure.^b Blended CCF peaks.^c OHP = Observatoire de Haute Provence; OAC = Osservatorio Astrofisico di Catania.

Table 3. Radial velocity of the primary (more massive, v_p), secondary (v_s), and tertiary (v_t) components of RasTyc 1828+3506 from Aurelie (OHP) and FRESCO (OAC) spectra. The orbital phase has been computed only for the data of 2005 according to the ephemeris $HJD_{\text{inf.conj.}} = 2\,452\,001.408 + 7.595 \times E$, with zero phase corresponding to the inferior conjunction for the primary component.

H.J.D. ^a (2450000+)	Phase	v_p (km s ⁻¹)	Δv_p	v_s (km s ⁻¹)	Δv_s	v_t (km s ⁻¹)	Δv_t	Obs ^c
3261.35425	—	-75.11	1.17	37.34	1.27	-24.06	1.26	OHP
3571.41016	0.715	47.23	1.33	-95.86	1.36	-19.98	1.25	OHP
3572.36621	0.841	42.22	1.35	-79.96	1.16	-18.02	1.34	OHP
3573.37378	0.974	— ^b	—	—	—	-19.56	1.39	OHP
3574.40454	0.109	-59.63	1.34	21.01	1.83	-19.32	1.20	OHP
3575.42236	0.244	-93.37	1.15	53.36	1.15	-18.03	1.30	OHP
3576.43481	0.377	-70.82	1.71	34.91	1.34	-17.80	1.27	OHP
3577.36768	0.500	— ^b	—	—	—	-19.55	1.40	OHP
3578.36035	0.630	30.30	1.70	-67.73	2.82	-17.81	1.27	OHP
3579.36890	0.763	51.28	1.33	-99.08	1.18	-17.38	1.26	OHP
3580.35083	0.892	21.90	1.28	-65.14	1.34	-17.90	1.26	OHP
3581.38745	0.029	— ^b	—	—	—	-18.81	1.39	OHP
3582.36328	0.157	-83.31	1.60	32.82	1.22	-17.96	1.20	OHP
3583.37573	0.291	-92.79	1.34	51.14	1.36	-17.43	1.26	OHP
3648.39840	0.852	40.56	1.23	-82.21	1.04	-15.66	0.69	OAC
3657.36380	0.032	-43.51	1.24	—	—	-13.00	0.71	OAC
3927.49000	—	-66.97	1.64	— ^b	—	—	—	OAC
3931.45260	—	30.57	5.23	-82.14	2.13	-8.81	2.32	OAC
3932.46490	—	44.26	2.37	-96.87	2.68	-7.45	2.22	OAC
3940.42350	—	38.43	1.62	-98.48	1.11	-8.97	1.07	OAC

^a Heliocentric Julian date at mid exposure.

^b Blended CCF peaks.

^c OHP = Observatoire de Haute Provence; OAC = Osservatorio Astrofisico di Catania.

Table 4. Radial velocity of the primary (more massive, v_p), secondary (v_s), and tertiary (v_t) components of RasTyc 2034+8253 from Aurelie (OHP) and FRESCO (OAC) spectra. The orbital phase has been computed according to the ephemeris $HJD_{\text{inf.conj.}} = 2\,452\,010.7086 + 4.9538 \times E$, with zero phase corresponding to the inferior conjunction for the primary component.

H.J.D. ^a (2450000+)	Phase	v_p (km s ⁻¹)	Δv_p	v_s (km s ⁻¹)	Δv_s	v_t (km s ⁻¹)	Δv_t	Obs ^c
2475.51587	0.828	20.57	1.27	-43.24	1.41	-10.96	1.26	OHP
2482.39160	0.216	-50.12	1.42	29.29	1.28	-9.99	1.39	OHP
3213.54565	0.811	25.34	1.28	-47.15	1.36	-10.75	1.27	OHP
3214.55176	0.014	— ^b	—	—	—	-10.36	1.41	OHP
3215.54883	0.215	-50.62	1.28	27.43	1.41	-11.96	1.26	OHP
3216.51929	0.411	-31.46	1.28	5.58	1.44	-13.23	1.41	OHP
3261.42578	0.476	— ^b	—	—	—	-10.35	1.31	OHP
3261.59082	0.510	— ^b	—	—	—	-10.71	1.37	OHP
3262.40967	0.675	23.25	1.42	-45.85	1.42	-10.79	1.27	OHP
3264.55518	0.108	-35.53	1.36	13.24	1.43	-10.83	1.28	OHP
3265.35815	0.270	-49.28	1.28	29.36	1.28	-9.46	1.26	OHP
3265.60254	0.319	-45.91	1.42	24.57	1.42	-10.71	1.27	OHP
3266.34009	0.468	— ^b	—	—	—	-10.02	1.31	OHP
3267.31812	0.666	23.25	1.27	-45.01	1.48	-9.68	1.26	OHP
3268.33228	0.870	17.08	1.34	-39.55	1.43	-9.69	1.26	OHP
3570.51855	0.871	17.60	1.27	-39.72	1.27	-10.00	1.28	OHP
3571.46240	0.062	— ^b	—	—	—	-10.33	1.29	OHP
3572.46777	0.265	-50.64	1.28	28.86	1.40	-10.66	1.27	OHP
3218.52790	0.817	24.88	1.38	-46.29	1.57	-9.65	0.79	OAC
3219.52590	0.018	— ^b	—	—	—	-10.71	0.24	OAC
3220.53390	0.222	-49.63	1.07	27.41	1.07	-11.17	0.61	OAC
3224.54270	0.031	— ^b	—	—	—	-11.53	0.36	OAC
3225.52580	0.229	-50.25	1.82	28.06	1.62	-11.20	0.59	OAC
3256.57340	0.497	— ^b	—	—	—	-9.25	0.36	OAC
3273.38010	0.889	11.83	1.12	-38.13	1.32	-13.28	0.78	OAC
3275.41070	0.299	-48.73	1.04	26.07	1.14	-11.70	0.61	OAC
3279.34730	0.094	-30.29	1.27	13.36	1.44	-10.36	0.60	OAC
3281.39960	0.508	— ^b	—	—	—	-9.19	0.33	OAC
3285.45010	0.326	-46.27	1.07	23.98	1.14	-11.57	0.62	OAC
3354.34210	0.233	-48.64	1.05	28.44	1.13	-10.19	0.40	OAC

^a Heliocentric Julian date at mid exposure.^b Blended CCF peaks.^c OHP = Observatoire de Haute-Provence; OAC = Osservatorio Astrofisico di Catania.

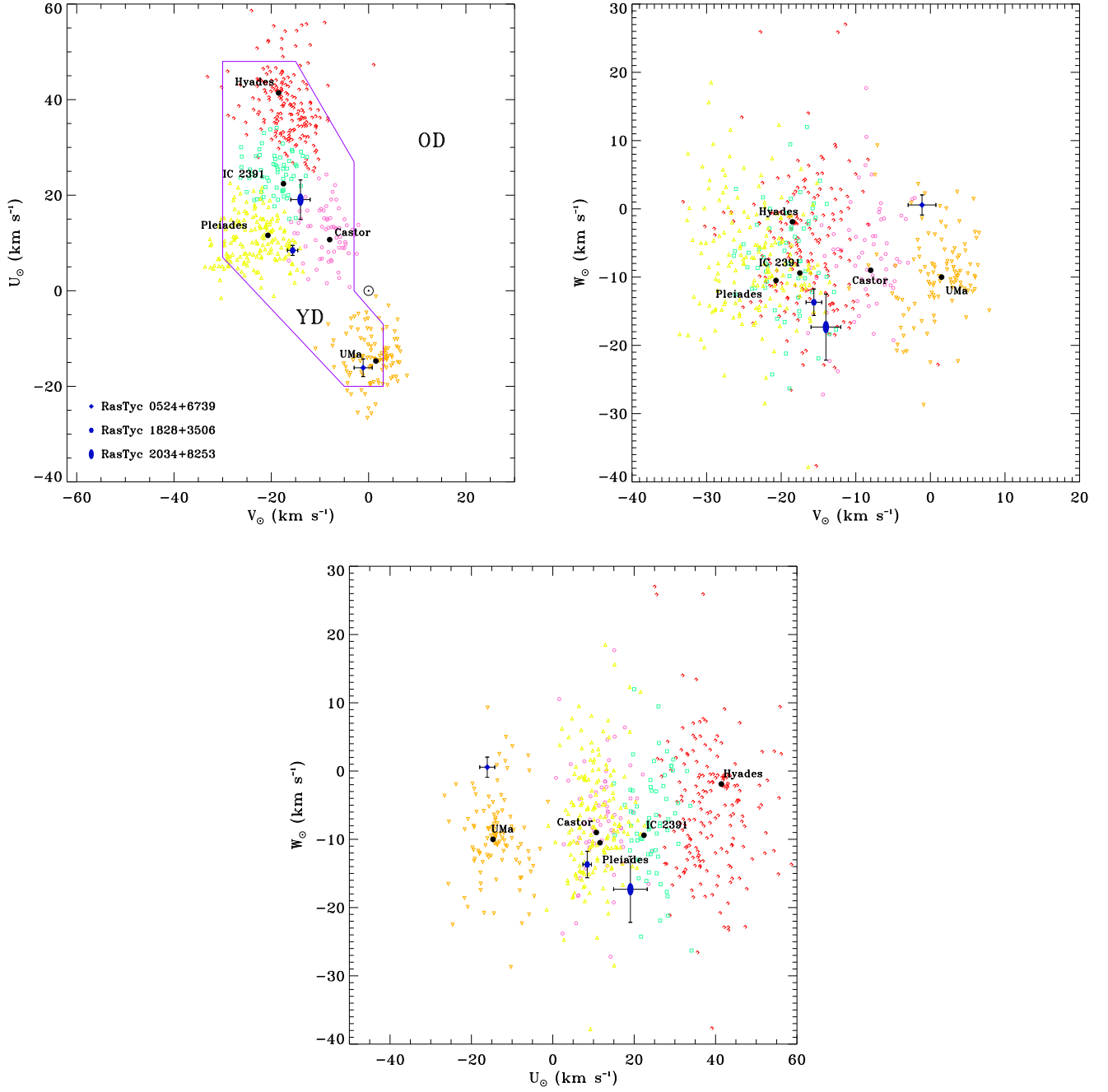


Fig. 8. The U – V (Left top panel), V – W (Right top panel), and U – W (Lower panel) diagrams of the *RasTyc* triple systems. The average velocity components (dots) of some young SKGs and those of some late-type stars members of these young SKGs (Montes et al., 2001) are also plotted (square, triangle, circle, upside down triangle, and U symbols for the IC 2391 supercluster, Pleiades, Castor, UMa moving groups, and Hyades supercluster, respectively). The locus of the young-disk (YD) and the old-disk (OD) populations (Eggen, 1996) are also marked on the U – V diagram.